UNCLASSIFIED

AD NUMBER
AD862927
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to DoD only; Administrative/Operational Use; JAN 1969. Other requests shall be referred to Air Force Rocket Propulsion Laboratory, Attn: RPRRE, Edwards CA 93523.**
AUTHORITY
AFRPL ltr, 5 Feb 1986

THIS PAGE IS UNCLASSIFIED

AD 862 827

AUTHORITY: AFAPL

ltr. 5 Feb 86

AD862927

AFRPL-TR-69-10

MINIMUM COST DESIGN (MCD) MATERIAL SCREENING

TEST REPORT NO. 1 - HAVEG 41

James A. Hintz, Capt, USAF

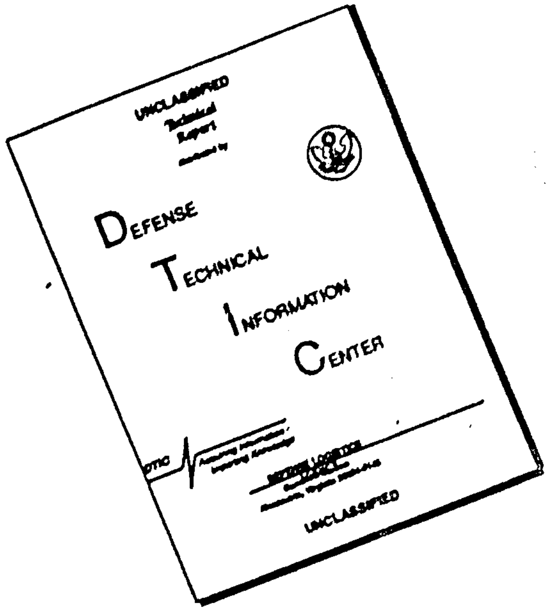
TECHNICAL REPORT AFRPL-TR-69-10

January 1969

Each transmittal of this document outside the Department of Defense must have prior approval of AFRPL (RPRRE), Edwards, California 93523.

AIR FORCE ROCKET PROPULSION LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

NOTICES

When U. S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

AFRPL-TR-69-10

MINIMUM COST DESIGN (MCD) MATERIAL SCREENING
TEST REPORT NO. 1 - HAVEG 41

James A. Hintz, Capt, USAF

FOREWORD

This report was prepared by the Engine Components Section, Engine Research Branch, and covers one of the articles tested in the Minimum Cost Design (MCD) Material Screening Program, Project Number 305803KRD. This project is under the technical direction of Capt J. Hintz, the Project Engineer. Others participating in the program include Lt D. Riedl, Lt A. Tsugawa, Mr. L. Tepe and Mr. G. Bergen.

Many of the items tested in this program are commercial items that were not developed or manufactured to meet government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

This technical report has been reviewed and is approved.

George Mushalko

GEORGE MUSHALKO, Major, USAF
Chief, Engine Research Branch
Liquid Rocket Division
Air Force Rocket Propulsion Laboratory

ABSTRACT

This is the first of a series of reports describing the results of test firings conducted to determine the performance of low-cost ablative materials which are candidates for use as thrust chamber and nozzle liners for MCD Booster engines. This report describes the test of Haveg 41, an ablative composed of phenolic resin and asbestos fibers.

Information pertinent to this particular test is included in the body of the report. A general description of the program and information common to all tests may be found in the Appendix.

The Haveg 41 test article survived the full planned test duty cycle. In general, the performance of this material in its initial screening test was quite good, and it will be a likely candidate for further testing under other environments later in the program.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

MINIMUM COST DESIGN (MCD) MATERIAL SCREENING

TEST REPORT NO. 1 - HAVEG 41

I. DESCRIPTION OF MATERIAL

Haveg 41 is composed of 60% phenolic resin and 40% asbestos fibers. It is a standard commercial Haveg material which is used primarily to fabricate tanks and pipelines for use in the chemical process industries. The material requires both temperature (300°F) and pressure (200 psi) to cure, and the cure is accompanied by about 2% shrinkage. Because of these cure characteristics, MCD chamber liners of Haveg 41 would be fabricated as molded segments which would be secondarily bonded into the pressure shell and joined together with Haveg 41F, which is an acid catalyst room-temperature-curing version of the same material. The Haveg 41 raw material costs approximately $2/lb, and the estimated cost of a Haveg 41 segmented liner in place is $7/lb.

Pertinent properties of Haveg 41 are as follows:

Specific Gravity	1.69
Coefficient of Thermal Expansion	6.3 X 10^{-5} in/in/°F
Coefficient of Thermal Conductivity	2.48 BTU/in/hr-ft^2-°F
Specific Heat	.32 BTU/lbm-°F

Haveg 41 has been tested in programs in support of MCD at Philco, TRW and Rocketdyne. In both the Philco and TRW programs, which were subscale screening programs in support of the AFRPL screening effort, this was one of the best materials tested because of the strong, erosion-resistant char which it forms and the relatively shallow char penetrations its low thermal conductivity affords. At Rocketdyne, the

material has been used for thermal protection of the 250K MCD Injector.

The Haveg 41 liner for the AFRPL screening program was fabricated and cured as a hollow one-piece billet of 5 in. I.D. and 10 in. O.D. which was machined to the standard screening liner contour (see Appendix Figure A-1) in the AFRPL machine shop. Six thermocouples were installed at various depths in the ablative material just upstream of the start of convergence.

II. TEST

The Haveg 41 liner was tested on 20 Nov 68 in run number 496 at the AFRPL test area 1-46-A1. The propellant combination was NTO/UDMH and the duty cycle consisted of a one-second checkout pulse to verify the operating conditions and the structural soundness of the liner, followed by a sixty-second continuous burn to establish erosion and char rates. The operating conditions during the sixty-second burn were as follows:

		Delivered	
	Target	Initial	Final
Pc [redacted] (psia)	195 [redacted]	197 [redacted]	161 [redacted]
Mixture Ratio	1.60	1.60	1.61
Thrust (lbf)	5200	5280	5330

The target operating conditions were selected on the basis of heat-transfer characterization tests with a copper calorimeter chamber so as to give a heat-transfer environment to the wall of recovery temperature in the range 3500 - 4500°F and convective heat-transfer coefficient in the range .0008 - .0010 BTU/in^2-sec-°F, which were the ranges of these parameters in the originally planned test matrix for this program. These conditions will be used in all the baseline screening tests in the screening phase of testing in this program (see Appendix). A more exact determination of the heat-transfer environment which these operating conditions provide to the ablative chamber wall will be made through more refined calorimeter chamber testing later in the program.

The shift in operating conditions during the long duration burn was caused by throat erosion and the lack of cavitating venturis in the flow system (see Appendix). Plots of the measured chamber pressure and calculated throat area as functions of time during the long-duration firing are shown in Figs. 1 and 2.

III. RESULTS

Visual inspection of the liner immediately after the 60-second firing revealed that no chunking had occurred, but that the surface recession which had occurred was uneven in some locations around the circumference of the liner. Most of the streaks which were present disappeared within the first 5 in. downstream of the injector face (Fig. 3), but two of them persisted into the throat and exit regions (Fig. 4). It was later determined that these streaks were caused by plugging of some injector orifices close to the periphery of the injector face giving rise to regions of extremely oxidizer-rich combustion near the ablative surface.

To determine the performance of the material in depth, the liner was removed from the steel shell and sectioned longitudinally in the center of the worst streak as well as in a region of uniform surface recession away from the streaks. Measurements of the char and surface recession were then taken along these cut surfaces.

The surface and char profiles in the non-streaking region are shown in Fig. 5, and represent the behavior of the material under the environment of the baseline operating conditions. In the chamber region there was very little surface recession, and the char front penetrated no further than .2 in. below the original surface. The char material was very strongly adherent to the virgin substrate material. Just below the char front was a heat-affected zone which was discolored and contained small cracks running parallel to the char front. In the throat region the total surface recession was .29 in., for an average of just under 5 mils/sec. Due to the high surface shear forces in this region the char layer was as thin

as .03 in., and there were no cracks or discoloration beneath the char front. The behavior of the material in the exit region was similar to that in the chamber.

The region of the worst streak may perhaps be considered as representative of the worst case of environmental non-uniformity which large-scale MCD injectors could have. In this region the surface in the chamber receded by as much as .75 in., which was also the total surface recession in the throat. Here the primary mode of surface material removal appeared to be chemical attack of the carbonaceous char by the oxidizer-rich combustion environment. The char layer down the entire length of this streak was on the order of .03 in. thick, and there was no visible evidence whatsoever of thermal penetration into the virgin material below the char layer.

A comparison of the traces from the six thermocouples which were embedded in the material with the visible thermal degradation of the ablative in the region of the thermocouples indicated that the particular thermocouples which were selected possess insufficient response capability to be suitable for gathering reliable data on the thermal behavior of the materials during the firing. However, these thermocouples will still be used in future test articles as a safety device to prevent complete burn-through of the liners whose resistance to surface recession proves insufficient to withstand the full 60 sec. planned test duration.

IV. CONCLUSIONS

On the basis of this test, Haveg 41 is a promising material and will be a likely candidate for further testing under other environments later in this program. However, sound conclusions as to the applicability of this material to the 250K long duration chambers (see Appendix) cannot be drawn until (1) the heat transfer environment of this screening test is more closely determined, (2) additional data is generated on this material under other environments, and (3) the environment provided by the 250K injector is determined.

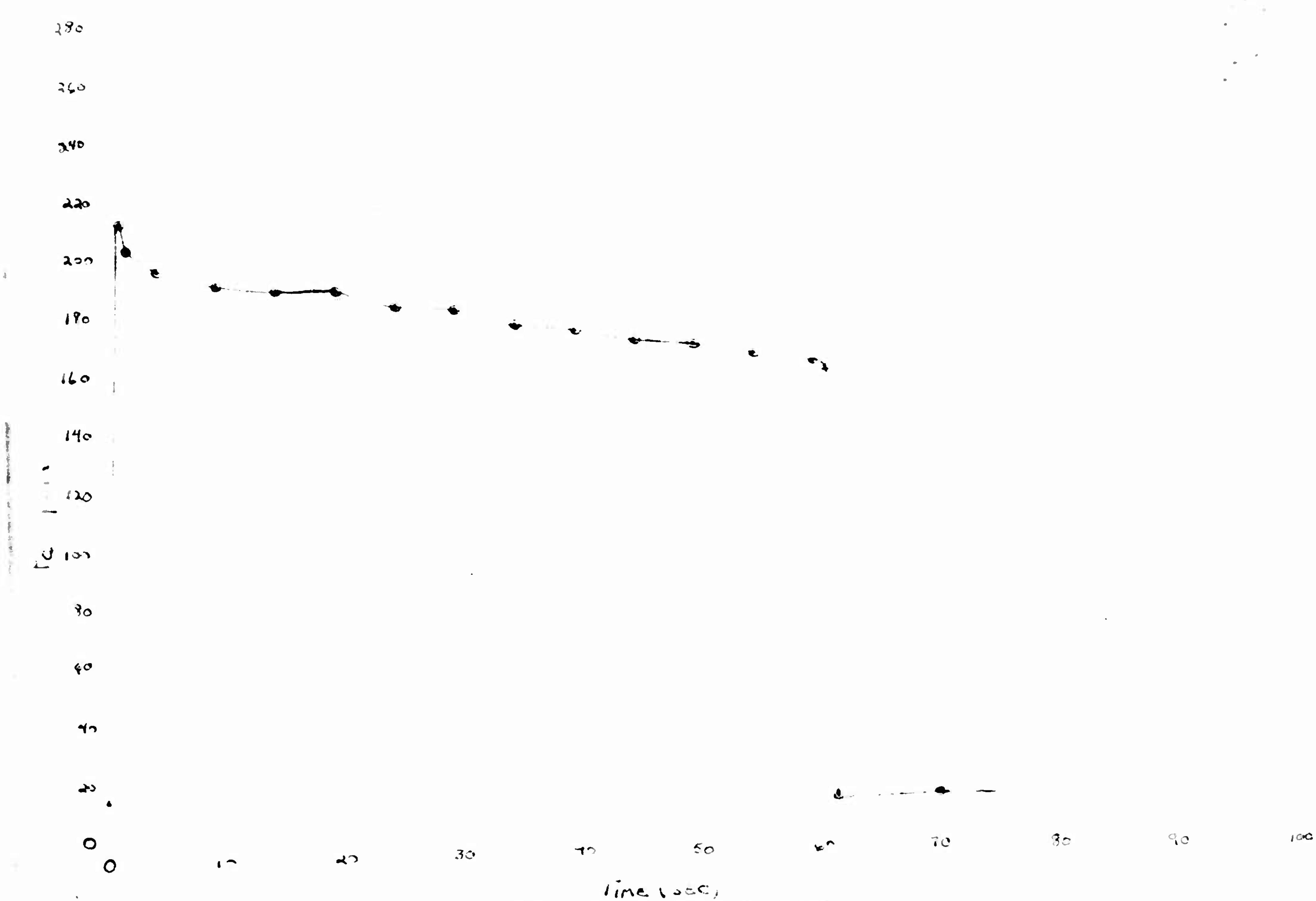


Figure 1. Pc versus Time, Run No. 496B. Haveg 41

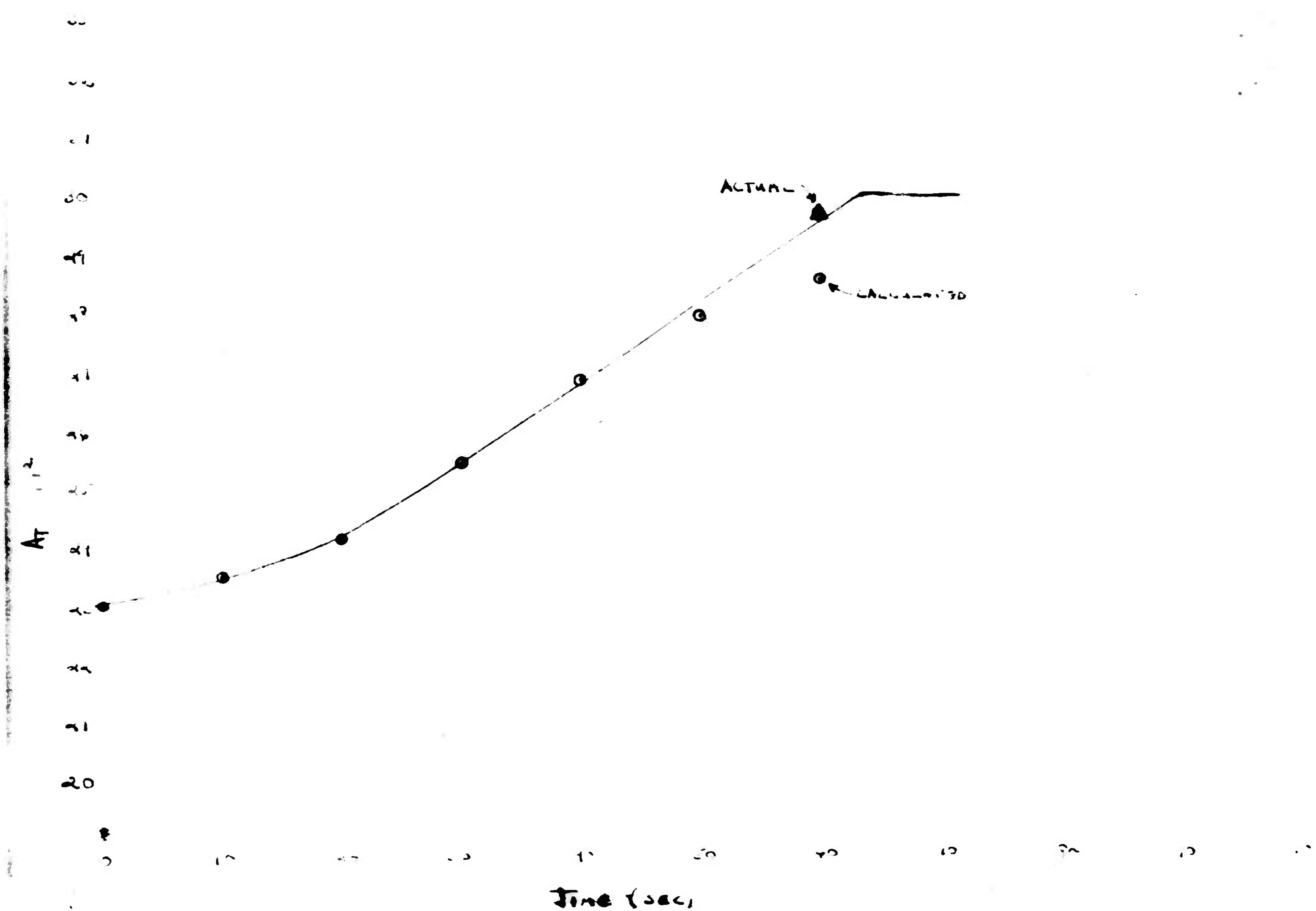
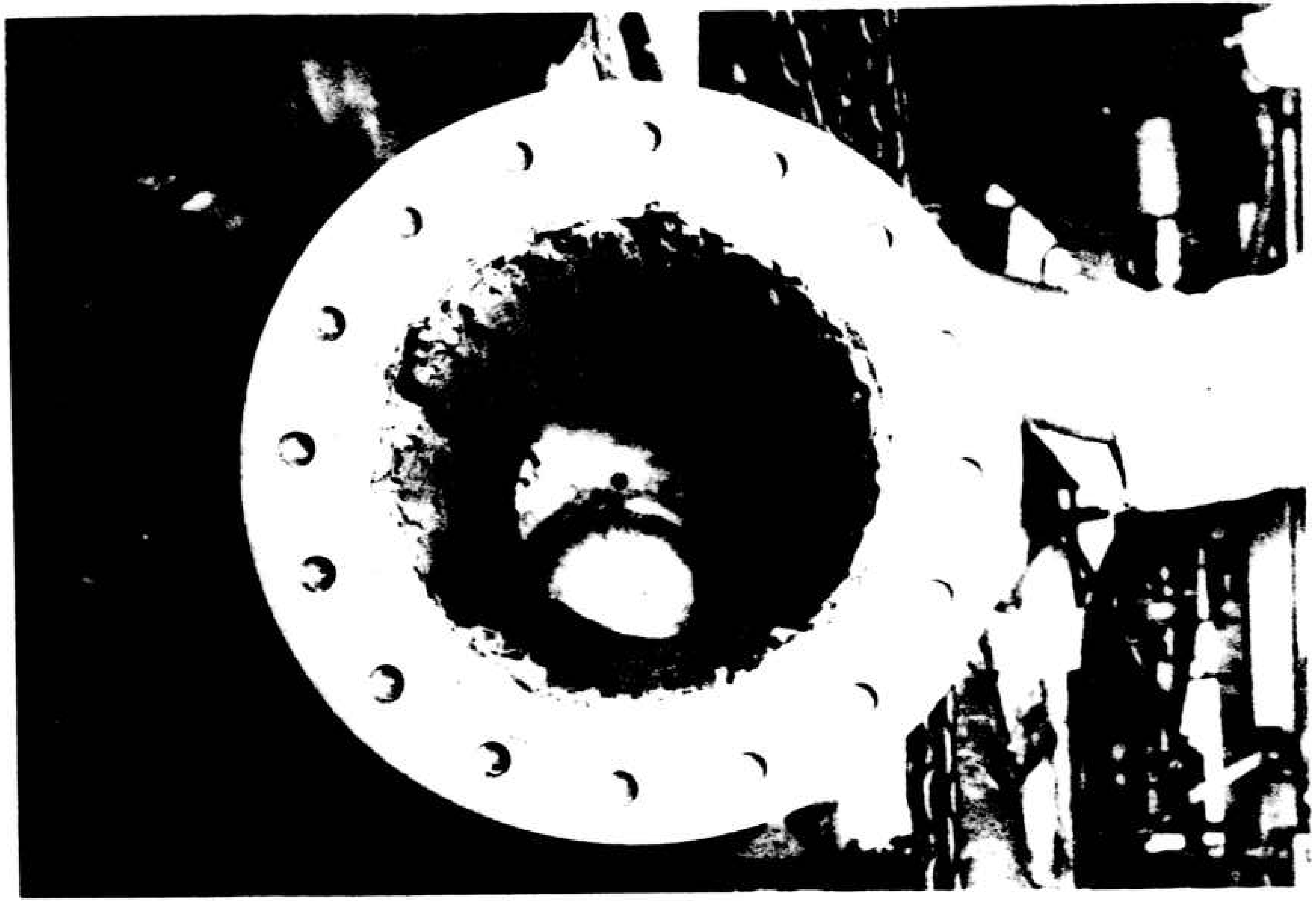


Figure 2. A_T versus Time, Run No. 496B, Haveg 41

OFFICIAL PHOTOGRAPH
AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIF.



8755 - 68 AFFTC 20 NOV. UNCL.
T.S. 1 - 46 A - 1 TEST # 1 MATERIAL SCREENING
RUN # 496, POST - FIRE PHOTO.

PHOTOGRAPH BY
A1C E.S. WEIN

Figure 3. Haveg 41 - From Head End

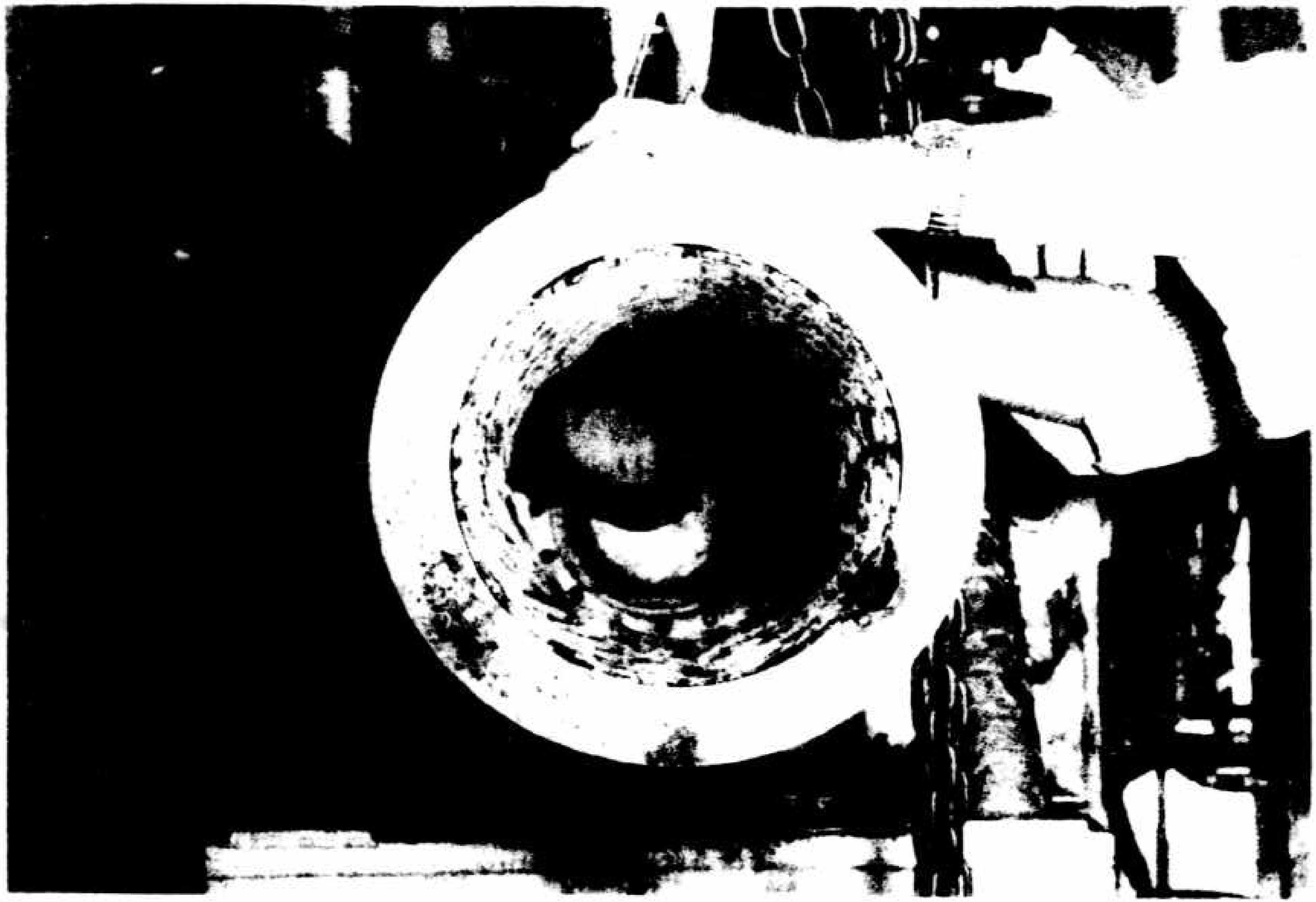


Figure 4. Haveg 41 - From Exit End

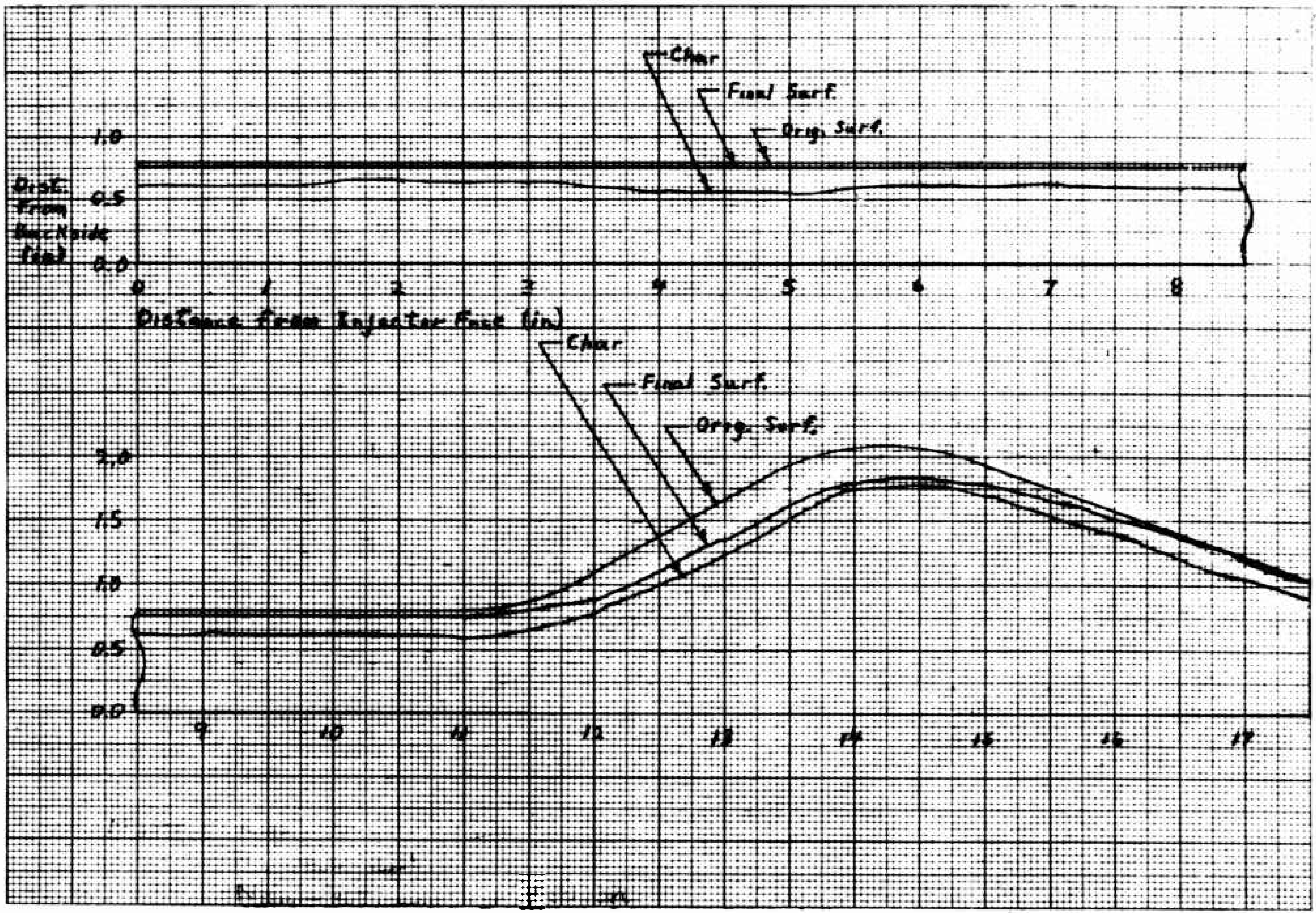


Figure 5. Run No. 496 - Haveg 41. Non-streaking Region, Surface and Char Profiles

SPEIDEL & CO. INC., FERNWOOD, PENNA.
20X20 TO THE INCH 5, 10, 20TH LINE ACCENTED

APPENDIX

PROGRAM DESCRIPTION

The objective of this program is to identify and generate design data on low cost ablative materials suitable for use as thrust chamber liners for MCD Booster engines. Candidate materials being tested not only have low raw material costs, but also lend themselves to low cost fabrication techniques such as molding, spraying or troweling. Candidate materials for this program are being identified in preliminary screening programs conducted by Philco Aeronutronics and TRW Systems as well as by a nationwide survey being conducted by the AFSC STLO system.

All testing of ablative materials in this program is being done in a subscale rocket engine using the NTO/UDMH propellant combination of the MCD Booster. The testing is divided into two phases. In the first, or material screening phase, which is scheduled from 1 Nov 68 through 30 Jan 69, approximately 15 candidate materials are being tested at a baseline set of operating conditions to identify those candidates worthy of further study. In the second, or materials characterization phase, which is scheduled from 30 Jan 69 through 1 Apr 69, the better materials from the screening phase are being retested at other operating conditions to characterize their performance as ablatives over the range of heat transfer, chemical and gas dynamic environments anticipated for the family of MCD Booster thrust chambers.

The injector being used for all testing has a pattern consisting of 481 like doublet elements on a 7.2 in. face diameter (see Figure A-1). This injector was selected because the fine pattern should present a uniform environment

to the ablative chamber wall with delivered C* efficiency not less than 95%, and the like doublet elements allow variation of the mixture ratio and chamber pressure from one operating point to another, without varying the resultant momentum angle, simply by varying propellant flowrates. The heat transfer environment along the ablative chamber wall at each of the operating points being used in the two phases of testing in the program is being characterized with workhorse calorimetry chamber hardware to aid in interpreting the performance of the ablatives tested.

The configuration of the standard ablative test article in this program is shown in Fig.A-2. The candidate ablative material is used in the nozzle as well as the chamber in order to gather erosion and char rate data in all regions in each test. The geometry is the same for all articles in the program, with changes in operating conditions being accomplished by changing propellant flowrates. In order to minimize the extent of chamber pressure decay as the ablative throat erodes during the firing, no cavitating venturis are being used in the flow system. The desired initial flowrates are being achieved by appropriate settings of the propellant tank pressures which then remain constant during the firing. Thus any enlargement of the throat during firing is accompanied by an increase in thrust and flowrates and a slight decay in chamber pressure.

Instrumentation used in each test measures thrust, chamber pressure at the injector face, injector manifold pressures and propellant flowrates. In addition to the low frequency pressure transducer used to collect chamber pressure data, there is also a high frequency Kistler pressure

transducer mounted on the injector face and connected to a high-frequency shutdown device to terminate the firing should high-frequency combustion instability develop. Thermocouples are embedded in the ablative material to monitor temperature rises as the thermal degradation of the ablative progresses during the firing.

The test of each article consists of a one-second checkout pulse to verify the operating conditions and the structural soundness of the liner, followed by a continuous burn of sixty seconds duration or until excessive thermal degradation of the ablative forces termination of the test, whichever comes first.

The end product of this program will be char and erosion rate data on promising ablative materials under a range of heat transfer, chemical and gas dynamic environments. This data will be used to select materials and size liner thicknesses for the long duration chambers in the AFRPL 250K Injector Scale-up Programs, which will in turn provide liner design guidance for MCD Booster thrust chamber development efforts which follow.

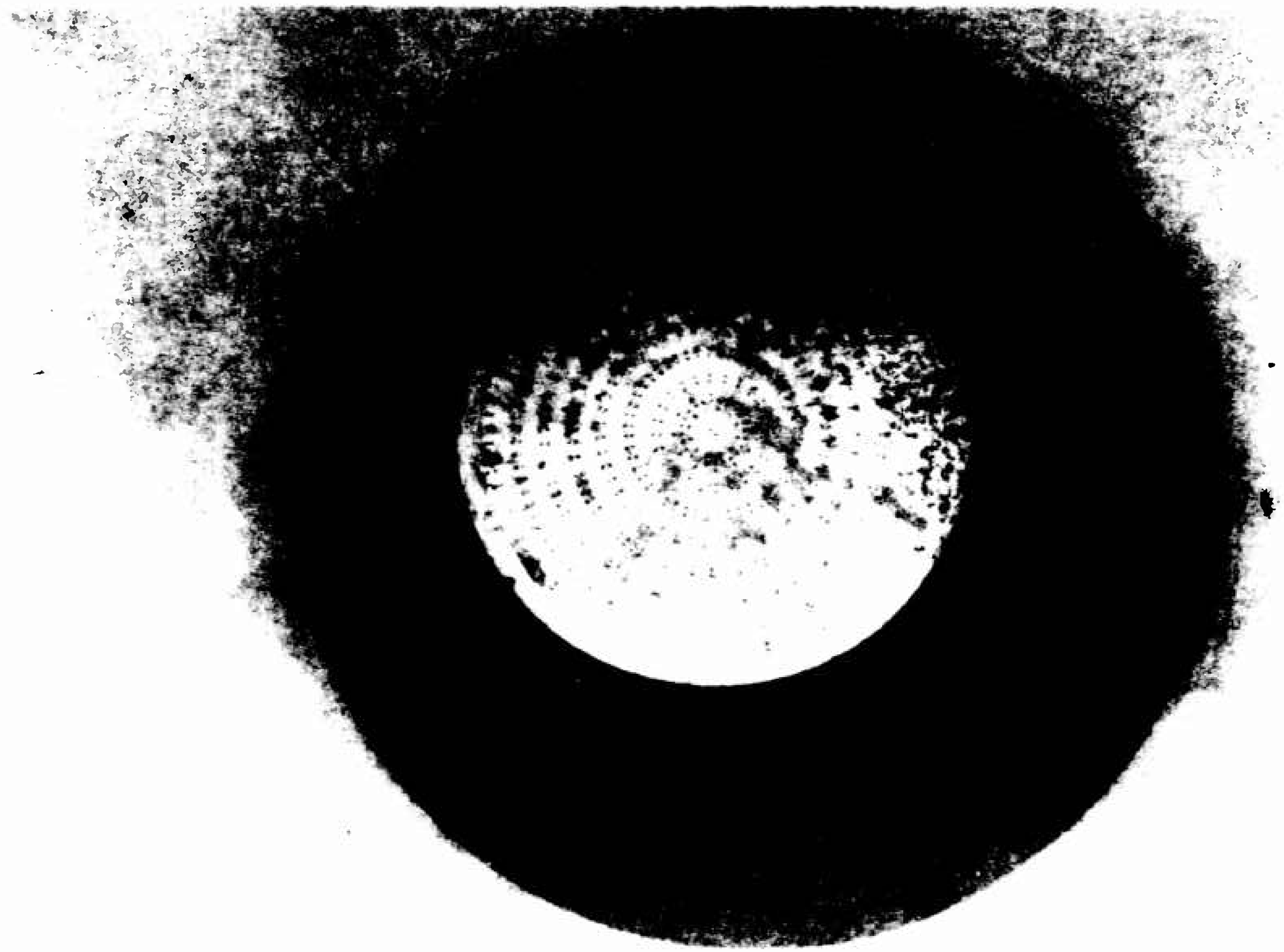


Figure A-1. Test Injector

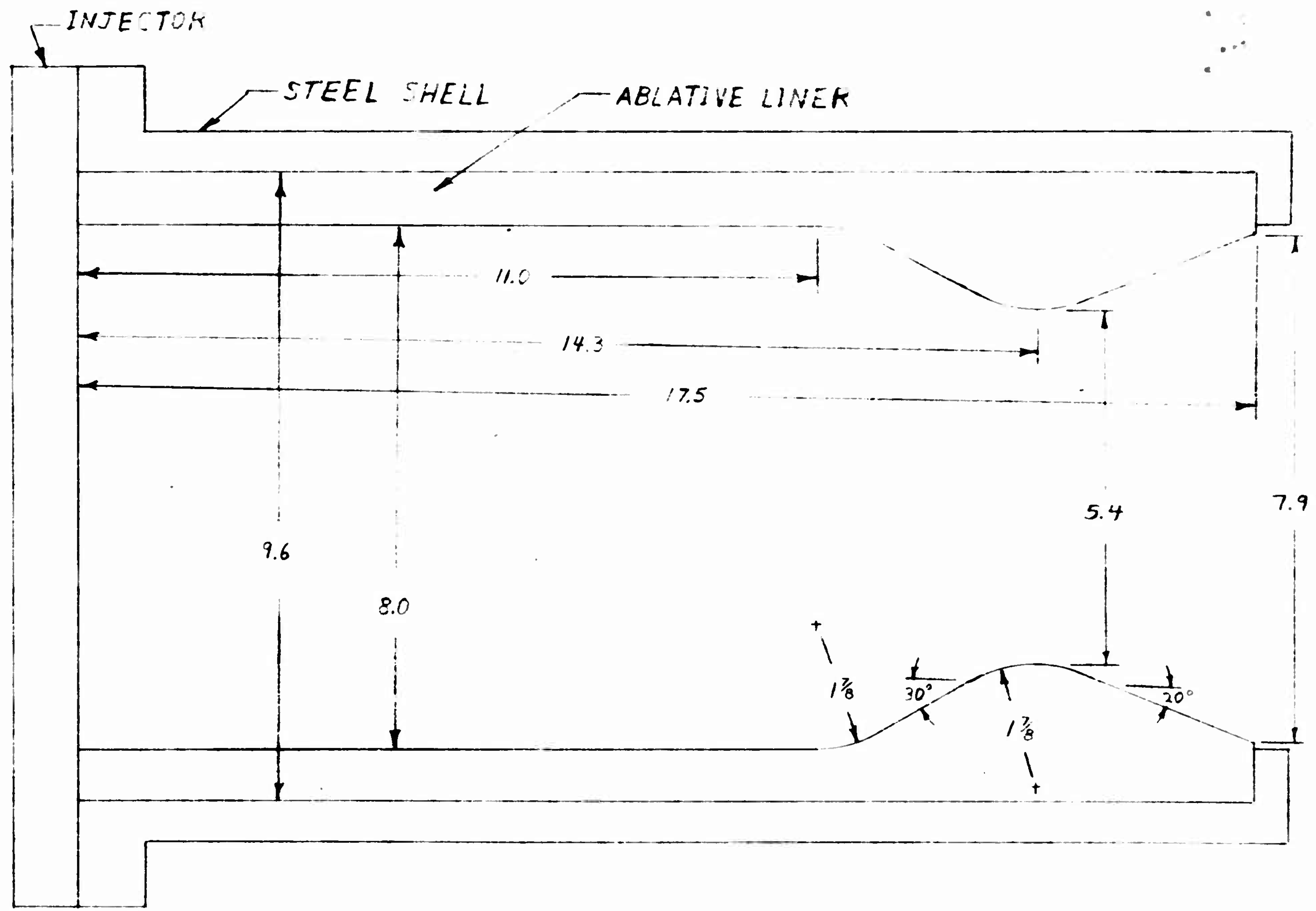


Figure A-2. Test Article Assembly

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Rocket Propulsion Laboratory Edwards, California 93523	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A
3. REPORT TITLE Minimum Cost Design (MCD) Material Screening, Test Report No. 1 - Haveg 41.	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) ~~Test Report—January 1969~~ Technical rept.	
5. AUTHOR(S) (First name, middle initial, last name) James A. Hintz, Capt, USAF	

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1969	~~20~~	None

8a. CONTRACT OR GRANT NO b. PROJECT NO. AF-305803KRD c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) AFRPL-TR-69-10 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
10. DISTRIBUTION STATEMENT Each transmittal of this document outside the Department of Defense must have prior approval of AFRPL (RPRRE), Edwards, California 93523.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Rocket Propulsion Laboratory Air Force Systems Command, USAF Edwards, California

13. ABSTRACT

This is the first of a series of reports describing the results of test firings conducted to determine the performance of low-cost ablative materials which are candidates for use as thrust chamber and nozzle liners for MCD* Booster engines. This report describes the test of Haveg 41, an ablative composed of phenolic resin and asbestos fibers.

Information pertinent to this particular test is included in the body of the report. A general description of the program and information common to all tests may be found in the Appendix.

The Haveg 41 test article survived the full planned test duty cycle. In general, the performance of this material in its initial screening test was quite good, and it will be a likely candidate for further testing under other environments later in the program.

* (Minimum Cost Design)

307 720

DD FORM 1 NOV 65 1473